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Assessment of the design of track drainage systems and culverts

Evaluation of design methods under consideration of changing precipitation events caused by climate change

- Summary -

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by

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1 Motivation

A continuous adaptation of the drainage systems to changing climatic conditions play a critical role for the Deutsche Bahn in ensuring both compliance for the track geometry as well as the serviceability and load-bearing capacity of the railway. Serviceability is especially restricted by water accumulation caused by underdimensioned or poorly functioning drainage systems, which negatively impacts load transfer. This results in nonconformities in track geometry and a reduction in serviceability. A loss in load-bearing capacity is also possible, e.g. if embankments become too waterlogged.

The underdimensioning of culverts can lead to the formation of hazardous backwater upstream of earthwork structures, which are then at risk of being undermined or inundated. This can lead to a loss in load-bearing capacity.

To combat these damaging effects and take into account a possible increase in severe precipitation events due to climate change, the inspection and adaptation of existing drainage systems as well as the design of new draining systems according to the current and continuously updated technical guidelines is necessary. To this end, the Federal Railway Authority initiated a research project with the following four work packages (WP):

WP 1 – Comprehensive historical review on the design of drainage systems and culverts
WP 2 – Mathematical review of the remaining hydraulic capacity of different types of drainage systems
WP 3 – Mathematical review of the hydraulic capacity of existing systems and development of adaptive measures
WP 4 – Development of possible recommended actions and adaptive measures

Chapter 2 provides an overview of the research results in the form of a categorization scheme for drainage systems and culverts. Chapter 3 presents the main findings regarding track drainage for open tracks, and chapter 4 the findings regarding culverts. Chapter 5 provides an outlook.

2 Overview of the research results

The draining systems and their components as described in the current technical guidelines RIL 836 (DB Netz AG, 2008) form the basis of the categorization presented here. Research was additionally conducted on the existing facilities under the supervision of the infrastructure management division (PD) Dresden and PD Magdeburg

The track drainage systems of the infrastructure management divisions are currently in the process of being catalogued and incorporated in the data management system of the DB Netz AG. Comprehensive access to the data on track drainage systems is therefore not yet possible.

Culverts on the other hand are largely categorized and available in the databanks of DB Netz AG. The PD Dresden represents a typical location in Germany, with track segments in both hilly and mountainous terrain. The PD is one of 34 PDs in Germany and supervises a total of ca. 1,500 km of track network. The PD Magdeburg contains primarily tracks in the plains and has a track network of ca. 1,300 km. Here, data are available for a total of 1,066 culverts, which can be used for comparison.

Based on the technical guideline RIL 836 and the research into the PD Dresden and PD Magdeburg, the drainage systems were summarized in Figure 1. The categorization of drainage systems is done from a hydraulic perspective with regard to their performance in the face of possibly climate-induced increased severe precipitation events. This is not to be confused with the categorization according to earthwork structures or other geotechnical structures.

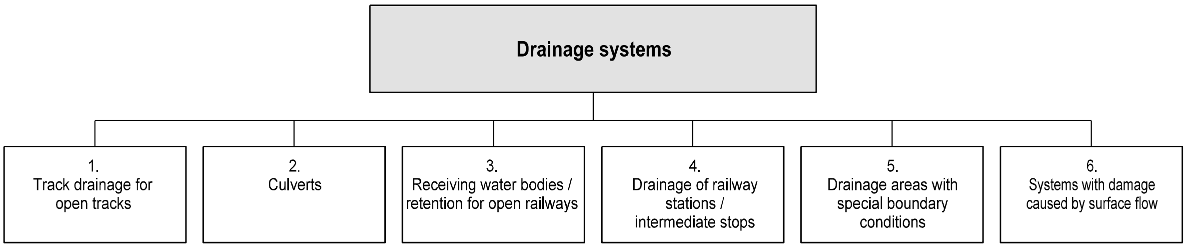

Figure 1 Categorization of drainage systems and culverts

Further analysis and hydraulic calculations were conducted for category 1: **Track drainage for open tracks** and category 2: **culverts**.

Categories 3 to 6 are as per agreement not part of this research project and are not included in this report.

3 Track drainage on open tracks

3.1 Research on Geometry and Design

Railway drainage systems have been conceived of since the beginning of the railroad era (1835). The hydraulic design of railway drainage systems including their components was not introduced until the mid-70s of the previous century. Initial design methods und specifications can be found in the “Provisional Guidelines for the Planning and Construction of Earthwork Structures for Tracks with Velocities above 160 km/h” (DB, 1979) and in the Guidelines for Deep Drainage (DR, 1976). The design parameters have since been continuously modified and the base rate precipitation $r_{15,1}$ has been updated. By contrast, the geometric design of drainage systems has hardly changed during the same time.

To calculate the remaining hydraulic capacity of existing drainage structures, the theoretical approaches of the two different calculation methods based on the static (time coefficient method) and dynamic models were compared and applied to different geometric boundary conditions and precipitation events with varying recurrence intervals. The impact of possibly increased severe precipitation events due to climate change was accounted for in the calculations.

Recent findings and research projects (e.g. Höntsch, 2003 and Below et al., 2008) show, that only a small part of the design peak run-off volume calculated by the time coefficient method in fact flows to well-functioning drainage systems, and that there is a time delay. As a consequence, the design flow volume is smaller, and furthermore it is received and drained over a longer period of time. This was corroborated by sample calculations in the area around the track as well as for outer catchments.

There is a large reserve capacity in the current hydraulic design of track drainage systems, both in terms of the input parameters for the calculation method (precipitation rate according to REINHOLD and peak run-off coefficient) and in the form of the:

- useable storage,
- natural retention capacity of unconsolidated rock (track ballast and material for the foundation layer),
- surface wetting of the ballast,
- consideration of infiltration rates,
- evaporation and
- use of pore spaces in the case of coarse-grained filters for the construction of deep drainage systems.

This reserve capacity is a significant advantage in light of a possibly increasing of severe precipitation events. It can therefore be assumed that a significant increase of precipitation can be received and drained without causing any harm to railway infrastructure.

3.2 Hydraulic Design

The various design methods and input parameters for the determination of precipitation run-off were closely investigated and compared in a parameter study based on the years 1988, 1991, 1999, 2008, 2019 and two assumptions for 2040. The calculation was performed using the travel time method for track lengths of 100 m, 500 m und 1,000 m. Peak run-off coefficients for the travel time method were determined for the external catchment and the track area using exemplary hydrodynamic calculations.

The design methods as applied to an open track were compared on the following aspects, taking into account the historical development:

- different design precipitation rates,
- surfaces with different run-off coefficients due to differing peak run-off coefficients
- different design flow rates as generated by the calculations.

The existing track drainage capacity was calculated in each case, with and without the influence of the external catchment, under consideration of the historical development of different technical guidelines and design methods as well as for varying precipitation frequencies. The resulting design flow rate and the drainage discharge capacity were plotted graphically (see example in Figure 2).

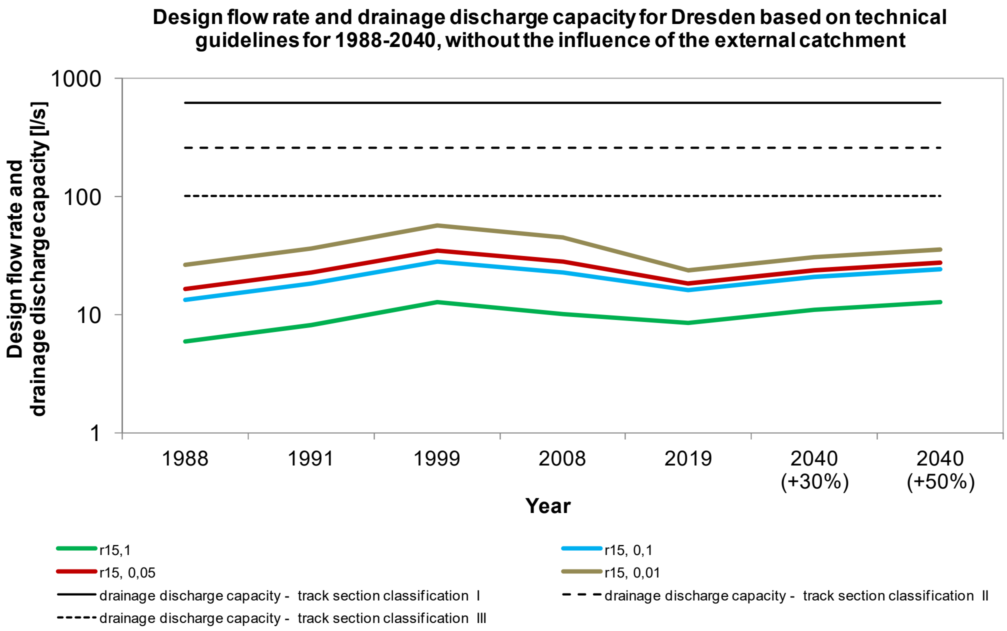

Figure 2 Comparison of the design flow rate and the drainage discharge capacity of a railway ditch for different classified track sections, without the influence of the outer catchment, track length 100 m, track bed slope 1 %

The evaluation for a length of 100 m and 1 % track bed slope show that depending on the track section classification and precipitation events, the drainage discharge capacity of the existing drainage systems for an open track will be sufficient, even in the future.

The calculations were also performed for the lengths of 100 m, 500 m und 1,000 m with variations in the track bed slope between 0.3 %, 1.0 % and 1.5 %, the results graphically plotted, and the capacity factor determined in percent. The results can be found in the final report for this project.

3.3 Case Study of an Open Track

Building on these findings, the hydraulic design and assessment of the drainage systems with regard to climate change was performed for a concrete case study with an open track. The chosen section is 242 m long and is located on the double-track section 6248 Dresden – Elsterwerda between km 17.873 and km 18.115 on the right-hand track, within the village of Weinböhla.

Calculations were made for four different model precipitation events and two natural precipitation events using the static and the dynamic model. The results show that in this case, as measured by the travel time method (static model), the drainage system has reserve capacity for severe precipitation events.

Calculations with the dynamic model showed that even a precipitation event with a return period of 100 years can be safely drained. Based on the input parameters for the dynamic model used in this research report, the drainage systems in this case are sufficiently dimensioned even with the assumption of a 30 to 50% increase of precipitation amounts in the future and with good maintenance should be able to reliably receive and drain the possibly increased precipitation rate caused by climate change.

3.4 Recommended actions

The travel time method is still applicable, provided the input values for the hydraulic design are accordingly adjusted. One option would be a decrease in the design flow volumes by adapting the conservative approaches of the travel time method or choosing another design precipitation rate, to achieve an economical design despite the possibly increased severe precipitation events caused by climate change. In the case of complex drainage systems as well as for the assessment of existing systems, the authors recommend the use of hydrodynamic models.

The maintenance of railway drainage ditches and deep drainage systems should have high priority. The importance of a well-functioning track drainage system should also be more actively and better communicated to other organizations and oversight bodies. Open drainage systems (railway ditches) should be favored over closed systems early in the planning phase.

Wherever possible, no outer catchments should be connected to railway drainage systems. For track section classes II and III, temporary standing water should be permissible for precipitation events with return periods of 20 to 100 years, as is currently the case for track section class I

The retention of the drainage element of deep drainage systems should continue to be considered as reserve capacity for severe precipitation events. To increase retention, the distances to the receiving water body could be reduced or larger ditches without pumping stations could be constructed instead of the standard railway ditch. The flow path from the drainage system outflow to the point of discharge into the receiving water body should be regularly inspected along with the drainage system itself.

In summary, the existing drainage systems as designed using the travel time method are sufficiently dimensioned. Owing to the design specifications from the current technical guidelines and the reserve capacity resulting from model results, both the existing drainage systems with standard cross-sections for open tracks with ballasted tracks and future systems based on the same design are able, without water accumulation, to receive and drain a design precipitation event $r_{15,\,0,1}$ with 50% greater intensity possibly caused by climate change. Regular inspections and maintenance measures are essential for a safe and backwater-free drainage. This applies not only to the drainage systems themselves, but also to the discharge path to the receiving water body as well as the point of discharge into the receiving water body.

4 Stream Culverts

4.1 Research on Geometry and Design

Research on the geometry and the construction methods of culverts was conducted on the example of the infrastructure management divisions (PD) Dresden and Magdeburg.

Research into the PD Dresden showed, that the culverts are largely categorized. Typical geometries include the circle, rectangle (or square) and an egg- or mouth-shaped profile.

A flowchart for an initial hydraulic estimation was developed for this study and applied to five selected examples from the PD Dresden to assess the remaining hydraulic capacity for the year 2019 as well as for an increase in flow rate caused by climate change.

The historical research showed that a requirement for the hydraulic design of culverts has existed since ca. 1985. The literature review showed that the technical guidelines historically contained and today still contain no specifications about the catchment that should be considered for the design of culverts.

Based on the evaluation of data from the PD Dresden and PD Magdeburg, however, it was possible to determine that standard geometric structures exist for culverts. The residual hydraulic capacity of these standard structures were assessed based on five examples from the PD Dresden, also in light of the increased severe precipitation events expected due to climate change.

A flowchart was created for the hydraulic design of culverts for the state of Saxony, which can be used for the initial assessment of the hydraulic capacity of culverts from today's point of view and in light of the possible increase in run-off flow rates. This is transferable to other states in Germany if data are available for precipitation rates and flow rates for water courses (as is the case in Saxony and Baden-Wuerttemberg) and can be made available in freely accessible internet portals.

Such internet portals are not yet available nationwide in Germany. One possibility for a nationwide initial assessment of design-relevant regional parameters is mentioned in the next chapter.

4.2 Recommended Actions

A general nationwide statement about the remaining capacity of culverts is not possible. Each site should therefore be individually assessed. However, general recommendations can be made about the construction methods, inspection and maintenance practices as well as the assessment of the remaining capacity in the face of higher run-off flow rates eventually caused by an expected possible increase in severe precipitation events due to climate change.

For the future hydraulic design of culverts, specifications should be made for the required level of safety under the consideration of economic aspects. It would be conceivable to use a flood event with a return period of 100 years (HQ_{100}) for newly constructed culverts. Information about current flood flow rates and predictions should always be obtained from the appropriate authorities.

In case no data are freely available, the tables and flowchart developed in the project and included in the final report can be used to perform an initial assessment of the hydraulic capacity. These could similarly be used to assess the capacity of culverts in case of renovation or in planning for the expected possible increase in flow rates due to climate change. Experience from previous flood events should always be included in these assessments.

With regard to construction measures, the authors recommend that culverts with double-channels be avoided and that in- and outflow points are firmly fastened, particularly in the case of changing flow directions, to reduce the risk of undermining. The cross-section and profile of culvert outflows should be adapted to the flow velocity. Inflow and outflow screens should not be employed, as even the smallest floating debris can lead to clogging and a reduction in the drainage capacity. In the absence of screens, small debris would usually flow through the culvert. Following flood events, culverts should be inspected and cleared of deposited sediment.

Existing railway embankments should not be used as flood protection dikes without geotechnical and hydrological assessment. However, the use of newly constructed railway embankments for flood protection is a possibility, given sufficient consideration of hydraulic design requirements.

5 Summary

This research effort investigated and evaluated the drainage systems for open tracks and stream culverts as well as their hydraulic design in the face of climate change. It was shown that particularly for existing track drainage systems of open tracks, the drainage of increased run-off flow rates is possible, even in case of severe precipitation events. This also includes a possible increase in both the intensity and frequency of severe precipitation events due to climate change. Regular inspections and maintenance measures are essential for safe drainage of run-off water. Example calculations were performed to show the sufficient hydraulic capacity of culverts and a possible method for an initial assessment of hydraulic capacity was developed. A nationwide evaluation of culverts is not generally possible, and must instead be done on a case-by-case basis. The consideration of certain construction methods at in- and outflow-points of culverts can increase its hydraulic capacity and reduce undermining.

Some special cases must be considered separately and occasionally on a site-by-site basis and cannot be accounted for in the standard design and evaluation practices in light of climate change. These special cases are listed in the final report.

With the exception of the case study „Weinböhla“, the evaluation of track drainage systems for open tracks based on the current common design precipitation rate with a duration of 15 minutes. Particularly unfavorable sequences of events were not considered and could also be considered for specific sites.

In addition to categories 1 (track drainage for open tracks) and 2 (culverts), four further categories were identified in this research report (see Figure 1). For these categories, there should be an in-depth evaluation of drainage systems and development of recommended actions as was done in this research report.

With regard to the evaluation of category 6 „ Systems with damage caused by surface flow”, a survey, compilation and evaluation of railway sections with damage events after severe precipitation events is conceivable.

For the example of the actual railway section in Weinböhla it would be possible to conduct a further calibration of model parameters based on the flow rates caused by severe precipitation events. All precipitation data known at the time of the final report’s creation did not provide any relevant flow rates.

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